RDECOM

TECHNOLOGY DRIVEN. **WARFIGHTER FOCUSED.**

CONDITION BASED MAINTENANCE
MORS 2008

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- Condition Based Maintenance Definitions

- AMSAA Focus

- Strategy – 4 Phases of Implementations
  - » Phase 1 – Development of EDHUMS
  - » Phase 2 – Implementation of EDHUMS
  - » Phase 3 – Development of Focused EDHUMS
  - » Phase 4 – Future Operations

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- # Condition Based Maintenance (CBM)
  - A plan of maintenance for a system based not upon time intervals but rather upon the actual condition of the system as enabled by the application of usage, diagnostic, and prognostic processes executed on a Health and Usage Monitoring System.

- # Health and Usage Monitoring System (HUMS)
  - A "smart black box" device installed on a system that acts as an enabler to CBM
    - acquires data from vehicle data busses, GPS, sensors, etc
    - turns data into information by executing algorithms to estimate the current health of the system on which it is installed and define the manner in which that system is being used and report this information to AMSAA for analysis and distribution.

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- **Collect Usage Data**

- **Develop algorithms to collect numbers of damaging events**
  - hard brakes, severe turns, etc.

- **Develop usage data summary reports**
  - get feedback from users, maintainers, fleet manager
  (i.e. what data do they need)
  - assist in identifying sources of vehicle failure and damage

- **Correlate field failure data to usage data and CBM outputs**
  - to develop specific component-level prognostics algorithms

- **Provide leadership decision support**
  - help determine cost-effective, timely, & beneficial CBM solutions

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Strategy: Two-Pronged Approach

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AMSAA Excellence in Analysis

Collect Data From Imbedded Onboard Sensors and Added Sensors

GPS
MOTION PACK
ENGINE BUS
TERRAIN SENSOR
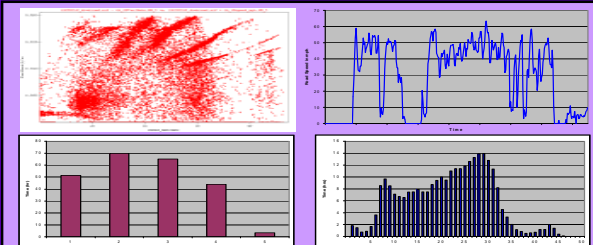
PROGNOSTICS

Feed data to Prognostics Algorithms

Report Impending Failures Unsafe or damaging usage
- Vehicle Driver
- Maintainers
- Commanders

USAGE

Compile and Report Usage Data To
- Fleet Managers
- Engineers
- Logistics

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17 September 2008

Strategy: Parallel Development - Two Environments

- **The Test Environment**
  - Allows for intensely-instrumented vehicles tested under many scenarios
  - Allows measurements to be made in a controlled and well-defined environment on known test courses
  - Provides large data sets for damage models and prognostic algorithm development
  - Allows use of industrial-grade equipment – no military-grade enclosures needed

- **The In-Theater Environment**
  - Provides immediate value by giving insights into vehicle usage while detailed usage/prognostics algorithms are being developed
  - Provides "lessons learned" in regard to in-theater installation possibilities and challenges
  - Sensitizes all involved to the realities of the in-theater environment and its implications
  - Provides a validation and verification platform for algorithms

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- ## Phase I (Complete)
  - No CBM platform existed for engineering development purposes
    -- identified appropriate hardware and software for EDHUMS
    -- large scale data collection, prognostic and usage algorithm development
  - Initial in-theater installations of data acquisition systems

- ## Phase II
  - Develop robust military-grade EDHUMS & data analysis process **COMPLETE**
  - Test EDHUMS in CONUS training environment **COMPLETE**
  - Field EDHUMS in operational units OCONUS including CENTCOM AOR **COMPLETE**
  - Develop information management process **IN-PROCESS**

- ## Phase III
  - Identify a small, inexpensive Focused HUMS (**FHUMS**) **COMPLETE**
  - Integrate FHUMS into established process **IN-PROCESS**
  - Widespread installations 1-5 EDHUMS and 5-25 FHUMS per installation **FUTURE**

- ## Phase IV (Future)
  - **Two options:**
    - Integration of proven FHUMS *hardware* into platforms by OEM at time of manufacture
    - Integrate proven FHUMS *capabilities* into other appropriate proven hardware

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- **Hardware:**

  - **Small, versatile, COTS data acquisition core**

    - nCode/Somat eDAQ-Lite

  - **1708 data bus and 1939 data bus**

    - Engine and transmission parameters

  - **GPS**

    - long, lat, alt, time, etc. (built into data acquisition box)

  - **6 DOF sensor ("motion pack")**

    - 3 axis accelerometer

    - roll, pitch, yaw

  - **Unsprung-mass accelerometer**

    - Terrain Identification

- **Data Files:**

  - **Histogram and fatigue rainflow cycle counting data can be stored indefinitely**

  - **Time history data can be stored for approximately 20 consecutive days**

  - **Download to laptop via wired or wireless Ethernet**

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- **Test-bed Hardware evaluation April-July '05 (YPG)**
  - Piggy-backed on other testing
  - HMS, 3 accelerometers, 1 strain-gauge, multiple SAE J-1708 bus parameters, GPS

Successfully demonstrated
  - hardware and software capabilities
  - data quality checks
  - rudimentary usage characterization

- **Dedicated prognostics Sept-Dec 2005**
  - fully instrumented vehicle - over 80 analog channels, multiple J-1708 bus channels, GPS
  - run over all APG test courses (multiple times)

Provide detailed data for prognostic algorithm development
  - in process of identifying primary sensors for algorithm development
  - developing algorithms to relate loading measured from "external" sensors to primary prognostic system sensors
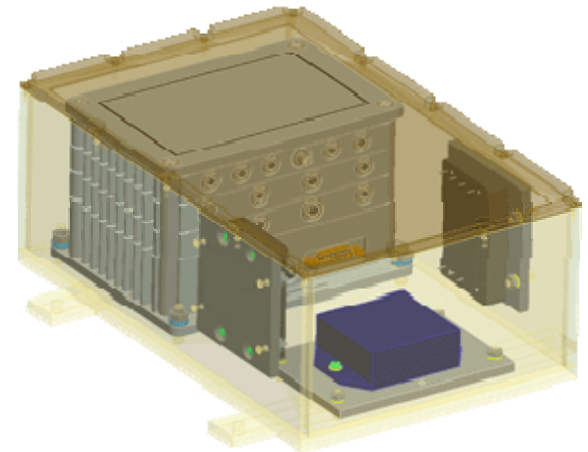

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- **ATC/AMSAA have measured and analyzed data from 20 wheeled vehicles of 3 different types in Iraq**
  - ➤ provided some usage data – no on-board algorithms for information generation
  - ➤ data being correlated with maintenance records
  - ➤ evaluate alignment of test to actual usage
  - ➤ evaluation inter-vehicle/mission usage variation
  - ➤ provided "lessons learned"

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Phase II: Robust Military-Grade EDHUMS
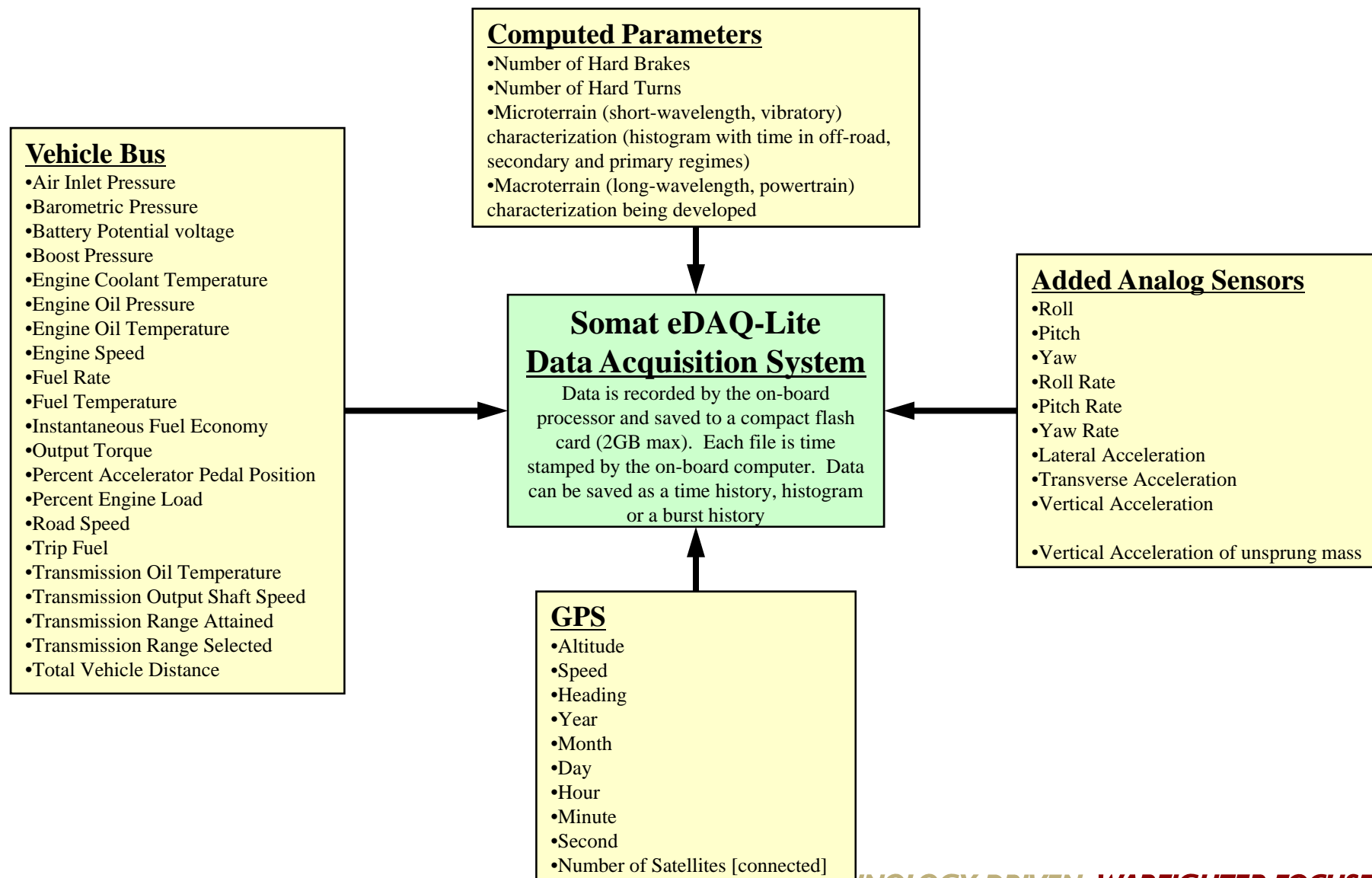
- **AMSAA made modifications to the Phase I Commercial Off The Shelf EDHUMS**

  - designed and built a military grade enclosure

  - provides enhanced survivability (thermal and vibration)

  - controls EMI to and from communications gear

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Computed Parameters
- Number of Hard Brakes
- Number of Hard Turns
- Microterrain (short-wavelength, vibratory) characterization (histogram with time in off-road, secondary and primary regimes)
- Macroterrain (long-wavelength, powertrain) characterization being developed

Vehicle Bus
- Air Inlet Pressure
- Barometric Pressure
- Battery Potential voltage
- Boost Pressure
- Engine Coolant Temperature
- Engine Oil Pressure
- Engine Oil Temperature
- Engine Speed
- Fuel Rate
- Fuel Temperature
- Instantaneous Fuel Economy
- Output Torque
- Percent Accelerator Pedal Position
- Percent Engine Load
- Road Speed
- Trip Fuel
- Transmission Oil Temperature
- Transmission Output Shaft Speed
- Transmission Range Attained
- Transmission Range Selected
- Total Vehicle Distance

Somat eDAQ-Lite Data Acquisition System
Data is recorded by the on-board processor and saved to a compact flash card (2GB max). Each file is time stamped by the on-board computer. Data can be saved as a time history, histogram or a burst history

Added Analog Sensors
- Roll
- Pitch
- Yaw
- Roll Rate
- Pitch Rate
- Yaw Rate
- Lateral Acceleration
- Transverse Acceleration
- Vertical Acceleration

- Vertical Acceleration of unsprung mass

GPS
- Altitude
- Speed
- Heading
- Year
- Month
- Day
- Hour
- Minute
- Second
- Number of Satellites [connected]
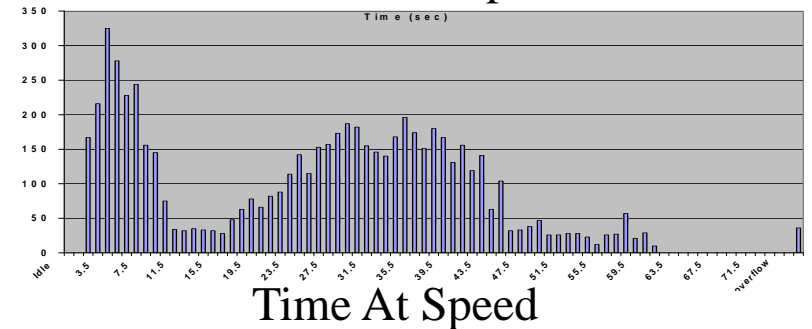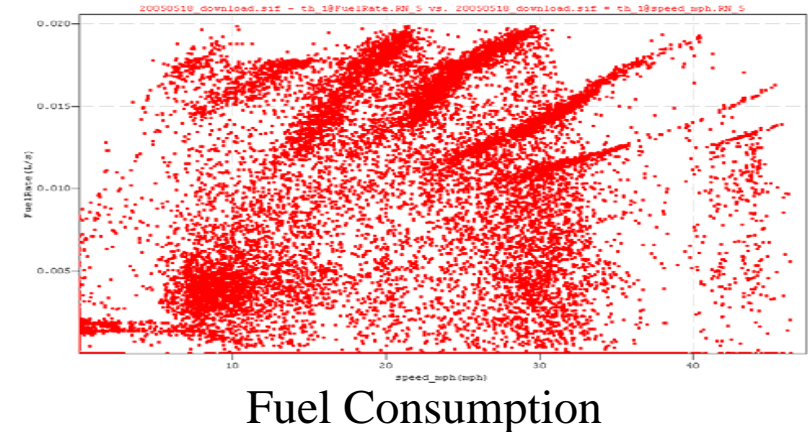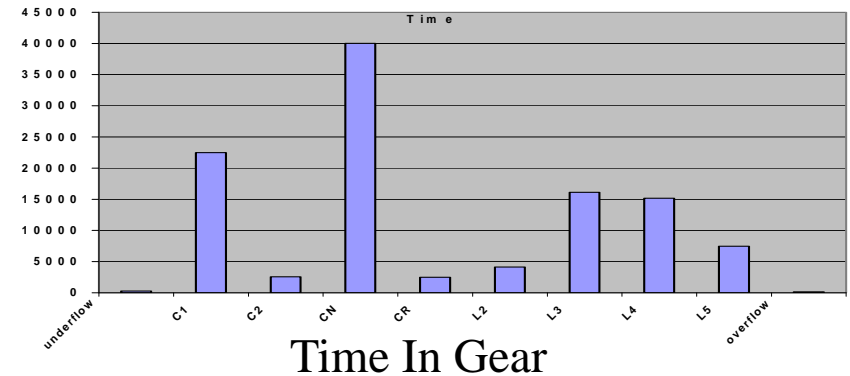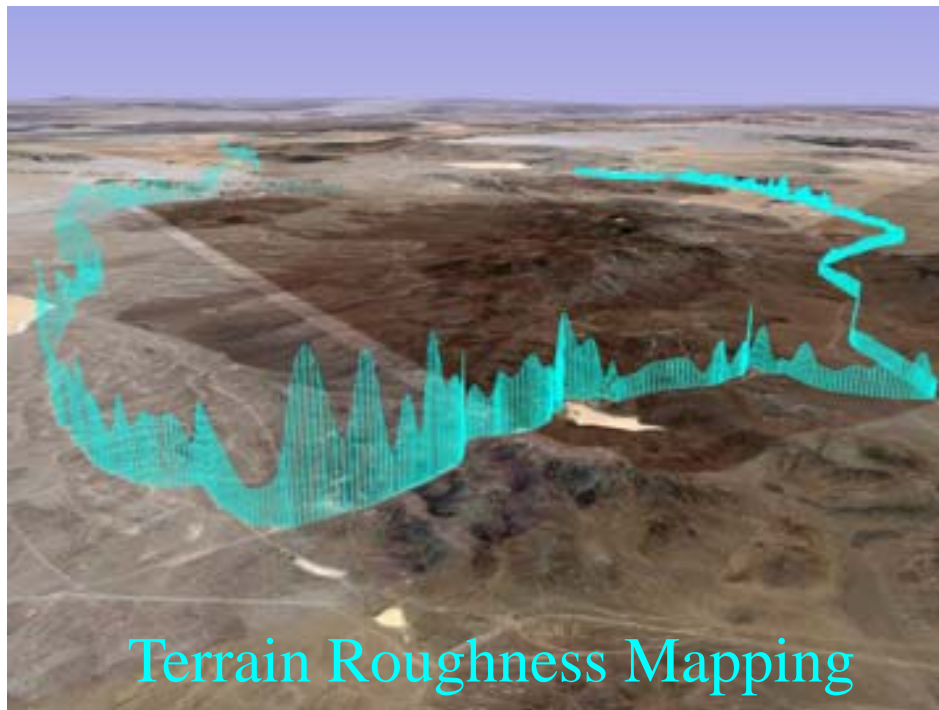
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- **Military - Grade EDHUMS testing completed Summer 2006**
  - On Tactical Wheeled Vehicles at National Training Center/Ft. Irwin, CA
  - Reducing, analyzing, and reporting data
  - Usage characterization algorithms installed and being refined

- **Two Iraq-Kuwait deployments in 06, 07 and 08**
  - Systems currently deployed in Kuwait, Iraq and Afghanistan
  - Systems currently deployed in multiple CONUS locations
  - More installations scheduled

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- # Sample analyses

  - ## large variety of time data

  - ## eight usage algorithms processed on-board

Terrain Roughness Mapping

Time In Gear

Fuel Consumption

Time At Speed

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REPORT PERIOD *
4/9/2008
START DATE: 1/22/2008
END DATE: 3/9/2008
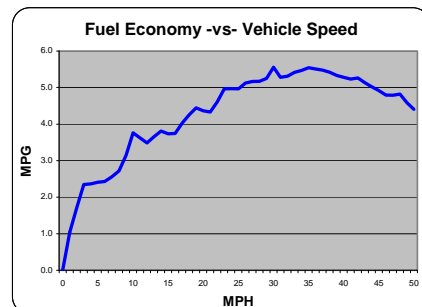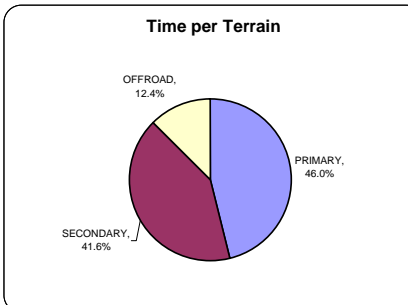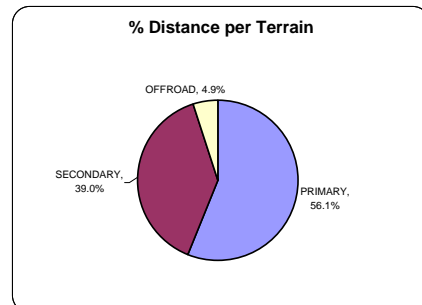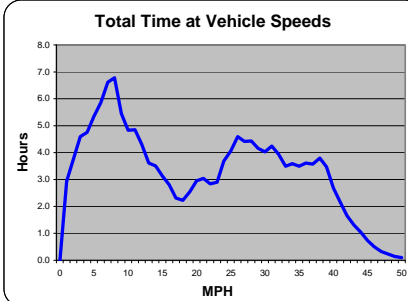* REPORT BASED ON 94 DAYS OF DATA.
(5 VEHICLES) - 19 DAYS OF DATA PER VEHICLE

GENERAL USAGE
MILES: 3479.5
ENGINE RUNNING TIME: 480.2 hours
TIME AT REST: 315.9 hours
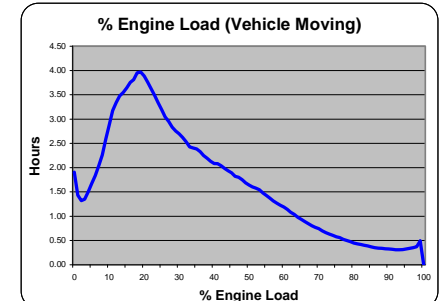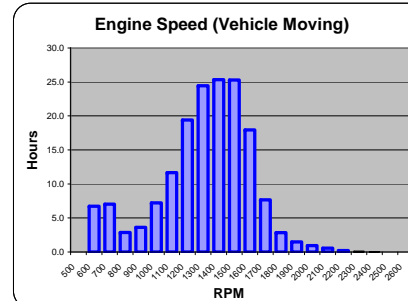% TIME AT REST: 65.8%

FUEL
TOTAL FUEL: 1031.2 (Gal)
FUEL USED AT REST: 268.3 (Gal)
AVERAGE MPG: 4.57 (excludes fuel used at rest)

Total Time at Vehicle Speeds

% Distance per Terrain

Time per Terrain

Fuel Economy -vs- Vehicle Speed

Fuel Economy -vs- Terrain
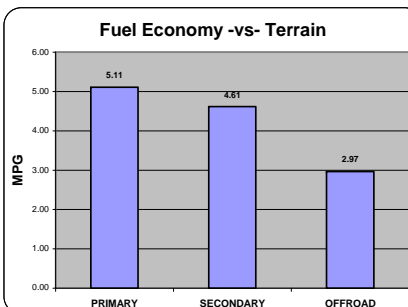
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ALL CAIMANS

4/9/2008

Engine Speed (Vehicle Moving)

% Engine Load (Vehicle Moving)

ENGINE
OIL PRESSURE < 15 PSI: 200 minutes
OIL PRESSURE > 80 PSI: 2 minutes
COOLANT > 250F: 0 minutes
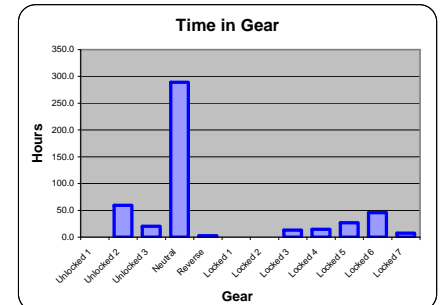ENGINE SPEED > 2300: 7 minutes

TRANSMISSION
OIL TEMP > 225F: 0 minutes

BATTERY
POTENTIAL VOLTAGE <12V: 42 minutes

CAVEATS
DATA RECORDING ERROR - 21 DAYS DATA LOST
RESOLVED 3/25/08
GMB400219E-KT NOT TAKING DATA

Time in Gear

MAINTENANCE PROFILE - TO BE ADDED

PAGE 2 of 2

- ## Objectives of a focused box
  - – Summarize parameters using histograms
  - – Exceedance measurements
  - – Reduced file size
  - – Perform same functions as current Soldier report

- ## Larger quantities
  - More comprehensive set of vehicle data
  - Fleet status

- ## Identified potential candidate
  - – Currently performing verification testing
  - – Currently developing algorithms to implement on box

Path Forward

- Install additional systems on TWV's
- Continue to develop small, inexpensive boxes
- Widespread installation of CBM onto a variety of ground platforms
- Continue to develop/refine diagnostic and prognostic algorithms
- Continue to develop/refine summary report template based on feedback

Questions

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- **Condition Based Maintenance**
  - A plan of maintenance for a **system** based not upon time intervals but rather upon the actual **condition** of the system as enabled by the application of **usage**, **diagnostic**, and **prognostic** processes executed on a **Health and Usage Monitoring System**.

- **System**
  - For vehicle systems, this includes not only the **vehicle** platform itself but also its **mission equipment**.

- **Condition**
  - Can be thought of as the current "**health**" of a system
    - What's "**broken**"
    - What's "**breaking**"
    - What's "**going to break**"

- **Usage**
  - the quantification of the manner in which the system is employed
    - hours running, miles driven, time at idle, fuel consumed, etc.
    - Use or abuse – indications of how and why things are **broken** or **breaking**

- **Diagnostics**
  - methods for finding what is **broken** and what is **breaking** in a system
  - based on symptoms / indicators of problems.

- **Prognostics**
  - Methods for predictively estimating when components are **going to break** - remaining useful life
  - based on a combination of indicators (when present) and /or physics of failure methods since indicators of failure are often *not* present.

- **Health and Usage Monitoring System (HUMS)**
  - A "smart black box" device installed on a system that acts as an enabler to CBM
    - acquires data from vehicle data busses, GPS, sensors, etc
    - turns data into **information** by executing algorithms to estimate the current health of the system on which it is installed and define the manner in which that system is being used and report this information to an integrated logistics system.

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